Report of the MSPG2 Study

Presented September 27, 2021 to MEPAG

MSR Science Planning Group 2 (MSPG2)

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This work was requested by means of the Terms of Reference (dated April 2, 2020) provided by NASA and ESA.

The decision to implement Mars Sample Return will not be finalized until NASA's completion of the National Environmental Policy Act (NEPA) process. This document is being made available for planning and information purposes only.

MPSG2 Overview

Timeline

- Terms of Reference signed by ESA and NASA in April, 2020
- Report complete July, 2021

Statement of Task

1. Provide inputs for an MSR Science Management Plan
2. Identify technical issues related to potential scientific usefulness of the samples
3. Develop high level requirements for the Sample Receiving Facility (SRF) to be used for cost estimation and budgeting
4. List key decision points related to the returned samples and represent them on a master timeline

Formation

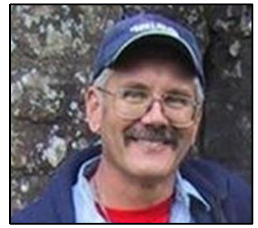
- Members competitively selected through joint NASA-ESA process
- International team comprised of 31 members representing 11 countries
  - Europe, United States, Canada, Japan

MSPG2 Team

Coordination Team


Michael Meyer


Gerhard Kminek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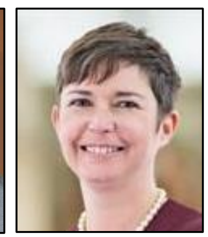
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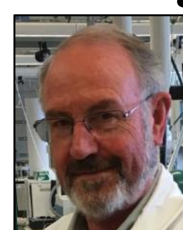
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Tim Swindle


Frances Westall

MSPG2 Results

1. Science Management Plan

- Demonstrated the need for an overarching MSR Campaign Science Program and proposed an implementation approach

2. Technical Issues

- Established which sample related activities would have to be conducted in the SRF, because they are time-sensitive, sterilization-sensitive, and/or are needed for initial sample characterization

3. SRF Requirements

- Provided technical requirements that would enable the SRF to meet its objectives and accommodate activities that cannot be done in external laboratories

4. Integrated Timeline

- Some aspects are pinned to the left side of the timeline, and others to the right side (i.e. either 2031 or 2033); The MSR Science Program comprises multiple types of activities - some are tied to the sample return date, while others are tied to the planning and activity of the flight missions, and some must start immediately

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Science Management Plan Development

The Challenge

- Agreements and funding for engineering elements of MSR have been established, but management, oversight, planning, and resources for scientific elements remain undefined

Findings & Proposed Solutions

- Science functionalities required to carry out MSR include:
  - Science leadership, science investigations, and involvement of the broader science community
- These functionalities are outside the scope of existing scientific bodies/activities
  - Some scientific functions covered by M2020, but most are not yet assigned
- New science bodies are needed for functionalities not yet assigned
  - Requires the establishment of an overarching MSR science management structure that should be initiated as soon as possible

Finding #1: A long-term NASA/ESA MSR Science Program, along with the necessary funding and human resources, will be required to accomplish the end-to-end scientific objectives of MSR.

Science Management Plan Guiding Principles

Transparency

- Access to samples must be fair and processes must be as transparent as possible

Science Maximization

- Management and sample-related processes must optimize the scientific productivity of the samples

Accessibility

- International scientists must have multiple opportunities to participate throughout the MSR process

Return on Investment

- Agencies providing the investments required to execute the MSR campaign should receive demonstrable benefits for enabling the samples' return

One Canister : One Collection

- The returned samples should be managed as a single collection even if housed in separate facilities

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The SRF: A Key Strategy

SRF

- Curation-related
- SSAP
- Time-sensitive science
- Sterilization-sensitive science that overlaps with above

OK to release unsterilized samples?

NO

Sterilize and release some samples

Uncontained laboratories

Sterilization-tolerant science

PLUS

Work on unsterilized samples in containment

Add contingency capability

Contained laboratories

Other sterilization-sensitive science

YES

Work on released unsterilized samples

Uncontained laboratories

All science not in initial SRF

Sample Curation & Initial Characterization

The Challenges

- All samples and hardware returned from Mars would need to be carefully handled, stored, and analyzed to minimize the alteration resulting from exposure to the Earth environment and maximize the scientific return
- In order for samples to be effectively allocated for scientific investigations, an initial set of characterization activities must be performed and a robust sample catalog must be created

Findings & Proposed Solutions

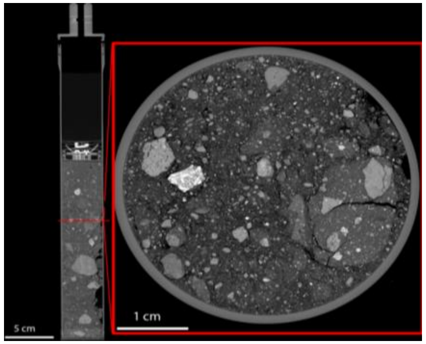
- Identify key functionalities for preserving scientific value of the samples
  – Maintain strict environmental controls, high levels of cleanliness, and contamination control & knowledge
- Identify key functionalities for initial sample characterization
  – Documenting state of tubes and samples prior to opening; tracking sample mass; preliminary assessment of main sample characteristics; preparation of a sample catalog
- Identify key functionalities for sample handling and distribution external to SRF
  – Enable pristine storage and sample allocation; distribute samples to international researchers

Finding: Traditional curation of extraterrestrial samples involves cleanroom operations, but MSR curation would need to be done concurrently with BSL-4-level containment. This would lead to complex first-of-a-kind curation implementations and require further technology development.

Curation - Initial Sample Characterization

3 Stages of Initial Sample Characterization

- **Pre-Basic Characterization (Pre-BC)**
- **Basic Characterization (BC)**
- **Preliminary Examination (PE)**

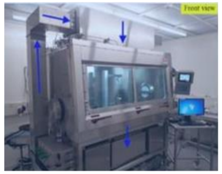


Pre-BC → BC → PE → Catalog

Non-pristine containment
Tubes sealed
All samples

Pristine containment
Tubes opened
All samples

Non-pristine containment
No tubes
Selected sub-samples



Dust removal

Measurements through the sample tube

Sample extraction
Secondary imaging/ weighing

Targeted Analyses

Time-Sensitive Investigations

The Challenge

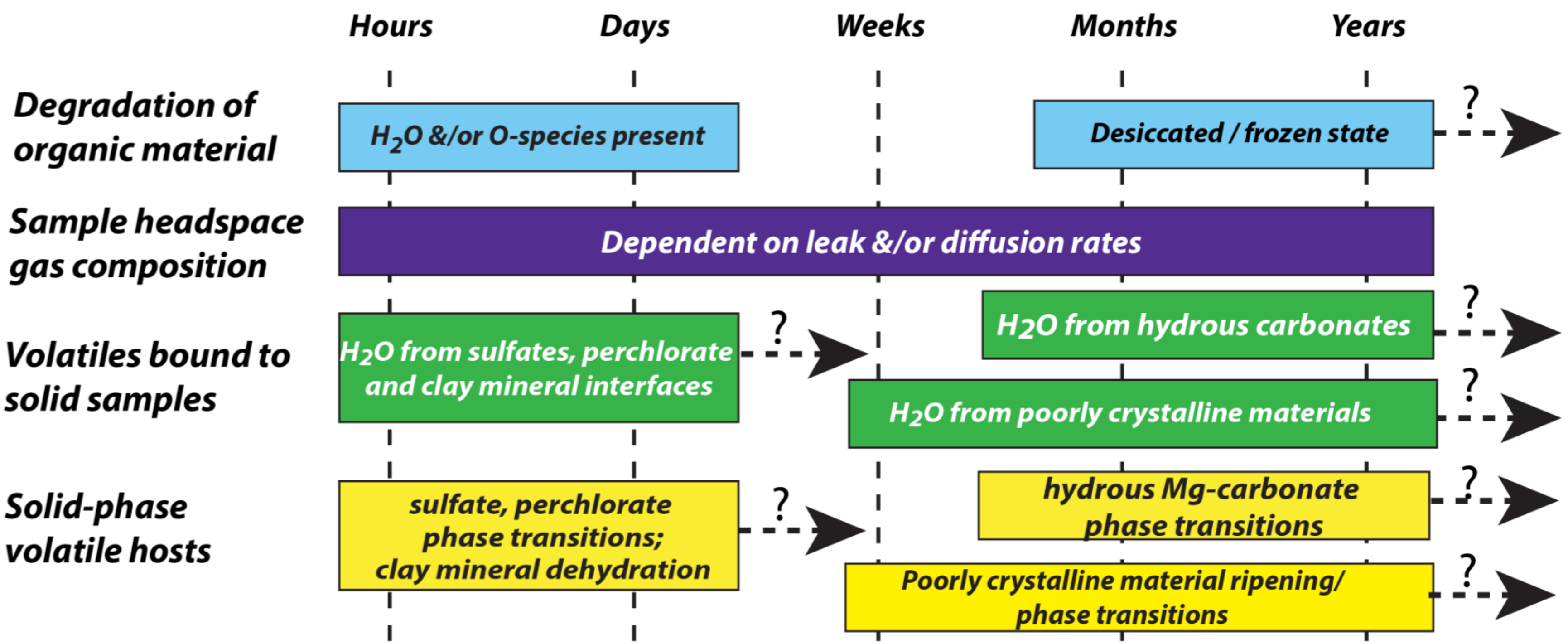
- Returned samples would be contained within the SRF until they are determined to be safe via the sample safety assessment protocol (SSAP), but breaking the sample tube seal will cause an equilibrium change that would cause irreversible changes over time
- If these science investigations are not made relatively quickly, valuable scientific information may be lost forever

Findings & Proposed Solutions

- Identify the processes that contribute to degradation of important sample attributes at timescales of several months or less:
  - Degradation of organic material, modification of headspace gas composition, mineral-volatile exchange
- Ensure that the SRF is capable of measurements required to investigate those attributes subject to degradation in order to minimize irrecoverable loss of scientific information
  - Characterize: Sample tube headspace gas composition, organic material, mineral-bound volatiles, and solid-phase volatile hosts

Time-Sensitive Science

- Characteristic timescales of processes that underpin the time-sensitivity of MSR measurements.
- We would need to move quickly once the sample tubes are opened



Sterilization-Sensitive Investigations

The Challenge

- Returned samples would be held in biocontainment until they are determined to be safe, or are rendered safe via sterilization processes that would permanently alter certain characteristics of the sample
- If measurements of sterilization-sensitive attributes are not planned for inside the SRF, valuable scientific information may be lost

Findings & Proposed Solutions

- Identify the sample attributes that are vulnerable to alteration via heat or gamma irradiation sterilization
  - Biosignatures of extant or extinct martian life, sample tube headspace gas composition, indicators of paleo-habitability and biosignature preservation, properties of volatile-rich and amorphous materials
- Identify overlap between time-sensitive science and sterilization-sensitive science
  - Potential biosignatures/organic material, sample tube headspace gas composition, properties of volatile-rich and amorphous materials
- Plan to conduct sterilization-tolerant science and sterilization-sensitive science that does not overlap with time-sensitive science outside of the SRF

Finding: Most aspects of MSR sample science could, and should, be effectively performed on samples deemed safe (either by test or by sterilization) in uncontained laboratories outside of the SRF. However, other aspects of MSR sample science would be both time-sensitive and sterilization-sensitive, including the search for life, assessment of habitability, and volatile exchange processes, and would need to be carried out in the SRF.

Implications for the SRF

- **This process was used to define a minimum set of measurements in the SRF that would be necessary and sufficient**
- **This was used to derive a minimum list of reference instruments for planning purposes**

SRF Measurement Categories

- Initial Sample Characterization
- Time-Sensitive Science
- Sterilization-Sensitive Science

Objectives

Instruments

Time-Sensitive (Tosca et al., 2021)	Goal 1. Characterize sample tube headspace gas composition			Goal 2. Characterize macromolecular material of potential biological origin (including volatile hydrocarbons)				Goal 3. Characterize mineral-bound volatiles			Goal 4. Characterize solid-phase volatile hosts			
Instrument	Extraction and handling of sample headspace gas	Concentration of major and minor gaseous species	Isotopic composition of major and minor gaseous species	High resolution *in-situ* chemical imaging	Stable isotopic ratios of gases in mixtures	Extraction and identification of organic molecules and polymers	Analysis and characterization of nucleic acids, proteins, lipids and metabolites	Detection / characterization of reactive O-species	Chemical and isotopic composition of mineral-bound volatiles	Volatile release in aqueous solution / chemical reactivity	Quantitative *in-situ* chemistry of volatile-bearing phases	Structure, degree of disorder of volatile-bearing phases	Detection / monitoring of structural water	Characterization / monitoring of ripening reactions
Gas extraction & handling equipment (e.g., vacuum lines, carrier gas)	xx													
GC-IRMS		xx	xx		xx									
Cavity ringdown spectroscopy or tunable laser spectroscopy*		xx	xx		x									
Confocal Raman microscopy (with UV fluorescence)				xx							x			
UHPLC-MS/MS						xx								
MALDI-TOF-MS							xx							
ESI-MS							xx							
DNA sequencer							xx							
Electron paramagnetic resonance spectroscopy (EPR)								xx						
Temperature conversion/elemental analysis-IRMS (TC/EA-IRMS)									xx					
ICP-OES										xx				
Ion chromatography										xx				
Field emission SEM-EDS											xx			
Raman spectroscopy (also required for confocal Raman microscopy)												x	xx	
FT-IR spectroscopy												x	xx	
Micro-X-ray diffraction												xx		x
Total scattering / pair distribution function analysis												xx		x
BET surface area analysis														xx

Example instrument traceability matrix

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Summary: Implications for the SRF

To support the scientific goals for MSR, the SRF would need to accommodate six broad functions:

1. Receive the spacecraft, and carefully de-integrate it layer by layer.
2. Provide an environment consisting of both BSL-4 equivalent containment, a very high level of cleanliness and contamination control, and physical security
3. Put all samples into a safe and stable state (including gas and dust), and complete the initial characterization of the samples
4. Enable specific scientific investigations, including those needed for the sample safety assessment protocol.
5. Enable the sample allocation and pristine sample storage processes
6. Support the transition to post-SRF activities, including analysis of samples outside containment and eventual transfer to uncontained curation facility(ies)

SRF Concept of Operations

RETURNED SPACECRAFT ARRIVES

M2020 sample dossiers, with field data

BIOCONTAINMENT BARRIER & PHYSICAL SECURITY

- Spacecraft Receiving
- Hardware de-integration

Sample tubes removed

- Exterior dust
- Pre-Basic Charact.

Work on sealed tubes

PRISTINE ISOLATORS

- Head gas removal
- Open sample tubes
- Basic Characterization

Storage of main sample mass

Highest Contamination Control

Unsterilized Sub-samples

SRF

High Contamination Control

Preliminary Examination

Sample Safety Assess.

Competed science

Some Sterilization-sensitive science

Time-Sensitive Science

- *Dossiers*
- *Pre-BC, BC, PE results*
- *PP Safety Report*
- *Scientific pubs*

Sample catalog

LABORATORY ENVIRONMENT OUTSIDE CONTAINMENT

Allocation of safe samples

RESULTS!

Translating the Vision into Requirements

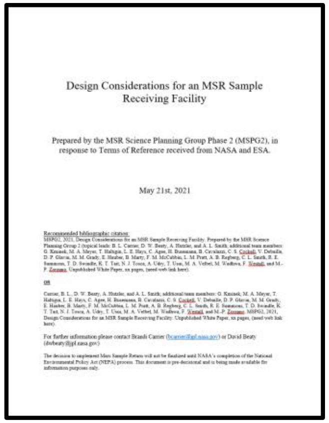
Curation → Focus group formed, report written, 15 findings

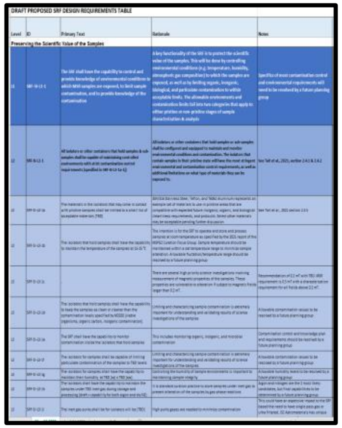
Time-Sensitive Science → Focus group formed, report written, 19 findings

Sterilization-Sensitive Science → Focus group formed, report written, 17 findings

Sample Safety Assessment → Worked on by COSPAR group, concluding Fall 2021

SRF Requirements Compendium





30-page report and draft requirements spreadsheet

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Timeline Considerations

The Challenge

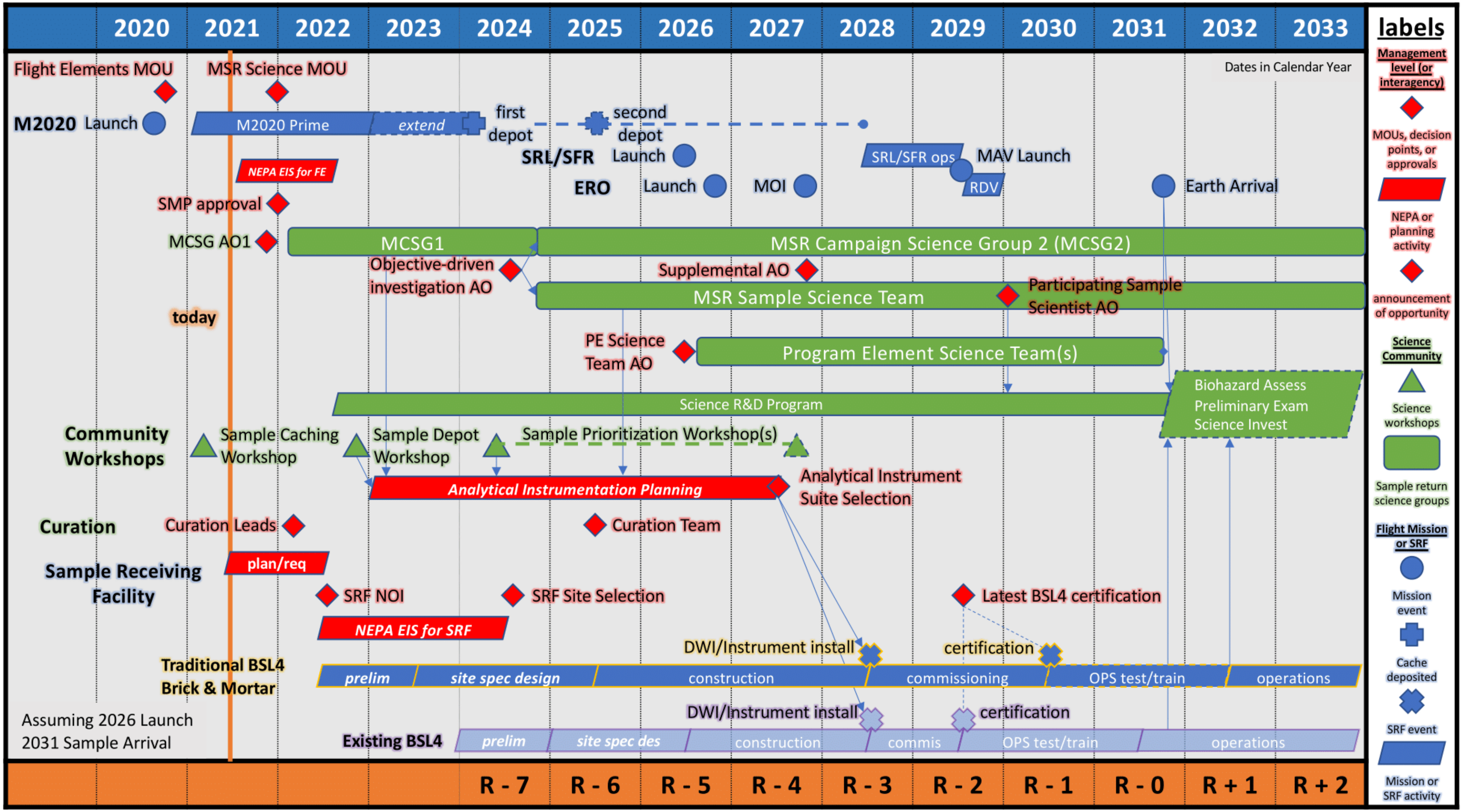
- The MSR Science Program comprises multiple types of activities - some aspects are tied to the sample return date, and others to the pace of activity of the flight missions.
    - Some aspects need to be worked at the same time as the planning of the flight missions—there are too many interfaces that cannot be managed correctly when we can see only one side. Some work needs to start NOW.
    - Clearly certain key planning deliverables need to be built around the sample return date.

The Proposed Solution

- Identify activities that must start immediately, regardless of return date
    - Establishment of Science Program and appropriate management agreements and bodies; preparatory research and development; initial SRF design requirements and trades
- Identify activities that can be delayed in the event of a schedule slip
    - Competition of sample investigations; population of flight element science teams (if applicable), certification of SRF

Finding: The schedule needed to get an SRF designed, constructed, and ready to receive the MSR samples has a longer lead time than perhaps anything previously attempted by NASA/ESA. It is important that preparations begin immediately; a potential delay in the return of the samples does not impact the overall science program planning beyond some shift in the mid-term activities.

Integrated Timeline (Shown for 2031 Return)



Pre-Decisional - For planning and discussion purposes only

Summary of Findings

1. A long-term NASA/ESA MSR Science Program, along with the necessary funding and human resources, will be required to accomplish the end-to-end scientific objectives of MSR.

2. Traditional curation of extraterrestrial samples involves cleanroom operations, but MSR curation would need to be done concurrently with BSL-4-level containment. This would lead to complex first-of-a-kind curation implementations and require further technology development.

3. Most aspects of MSR sample science could, and should, be effectively performed on samples deemed safe (either by test or by sterilization) in uncontained laboratories outside of the SRF. However, other aspects of MSR sample science would be both time-sensitive and sterilization-sensitive, including the search for life, assessment of habitability, and volatile exchange processes, and would need to be carried out in the SRF.

4. To meet the unique science, curation, and planetary protection needs of MSR —even with an explicit goal of performing as many MSR sample analyses as possible outside of biocontainment — substantial analytical and sample management capabilities would be required in an SRF.

5. The schedule required to have an SRF designed, constructed, and ready to receive the MSR samples has a longer lead time than perhaps anything previously attempted by NASA/ESA. It is important that preparations begin immediately; a potential delay in the return of the samples does not impact the overall science program planning beyond some shift in the mid-term activities.

Looking Ahead

Initiate the MSR Science Program

- Generate the documented agreements between NASA and ESA to define the end-to-end MSR Science Program (i.e., Science MOU and SMP) and seek the necessary funding and authority to implement them.

Establish the MSR Campaign Science Group

- Develop the Terms of Reference

Fund Research & Development for MSR Science Preparatory Activities

- Utilize and/or augment existing funding mechanisms or develop new mechanisms to support short- and medium-term technical studies required to carry out the MSR Science Program.

Advance SRF Science-Related Requirements

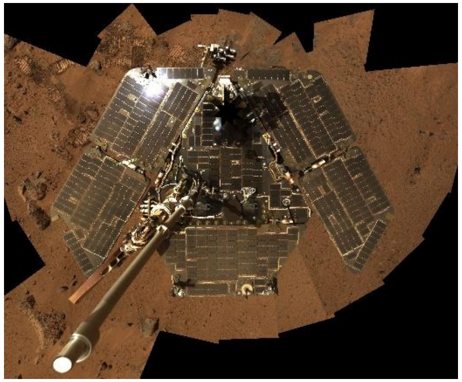
- Continue to refine the draft SRF science-related requirements, especially regarding environmental conditions, cleanliness contamination control, and priorities, and to translate them into an overall curation plan, facility concept, budget, and schedule, as input into SRF implementation planning.

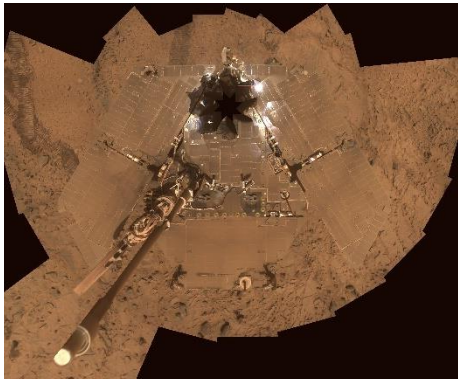
BACKUP

Additional Scientific Considerations

Dust Samples

- Two populations of martian dust exist that are distinct from the martian dust that is expected to be returned as part of a regolith sample collected by Mars 2020:
  - (i) airborne dust in the atmosphere; (ii) airfall dust that collects on surfaces;
- Each population has different potential for addressing scientific and technical questions of interest
  - Ideal case would be dedicated sample of airborne dust, but may be infeasible due to engineering constraints; second choice would be capability of preserving and investigating airfall dust that has collected on the outside of the sample tubes
- Every effort should be made to avoid removing the serendipitous dust that accumulates on the outside of the sample tubes, as long as it does not prevent the sample tubes from being successfully loaded into the OS



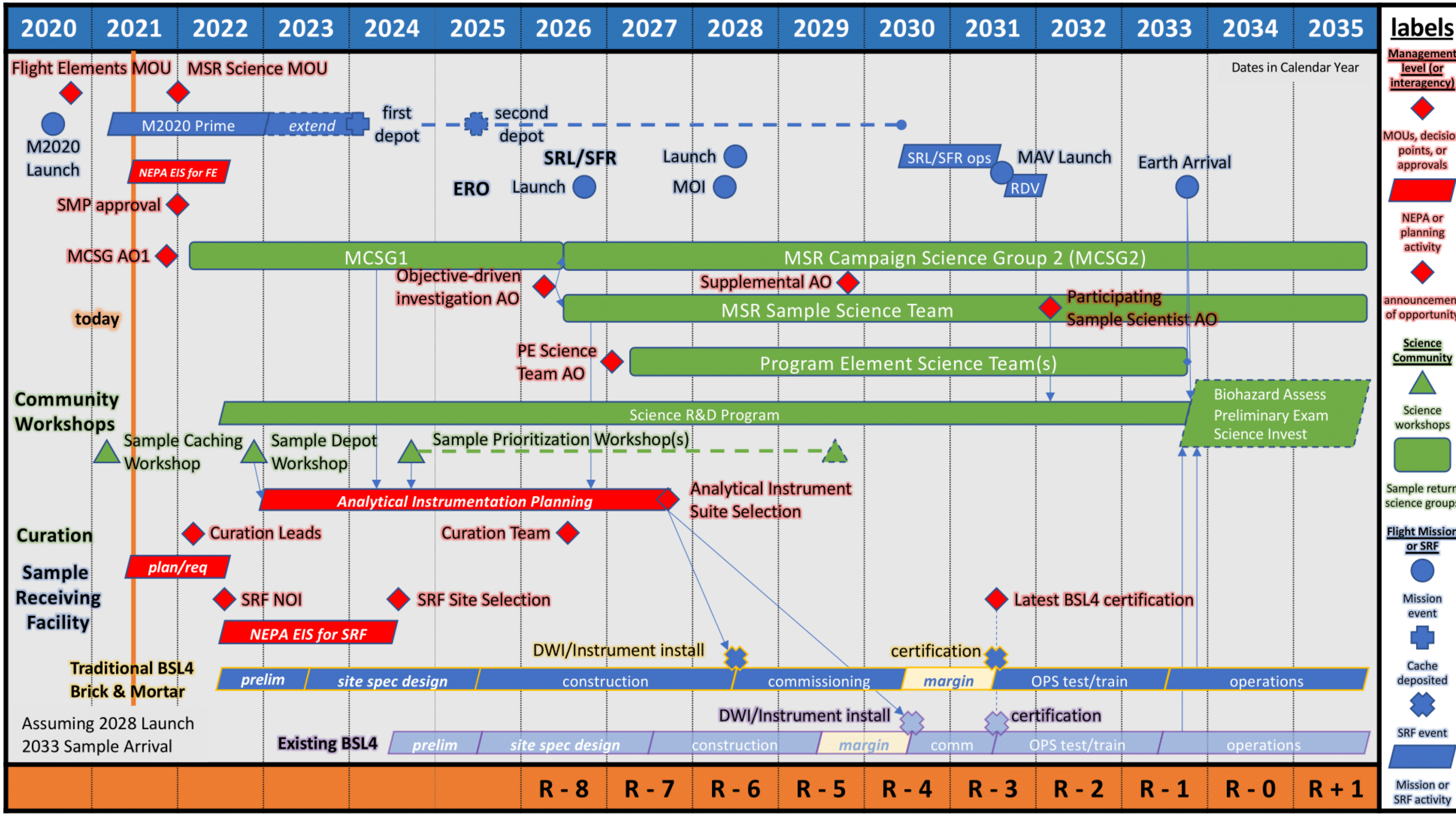


Additional Scientific Considerations

Atmospheric Gas Samples

- The headspace gas over solid samples collected by M2020 will be of significant scientific interest. However, several factors will limit its usefulness for atmospheric geochemistry investigations:
  - The quantity of gas is insufficient for many investigations
  - Likelihood of exchange between solid samples, headspace gas, and tube walls
  - Sample tube materials and preparation were not designed for optimal gas collection and storage
  - Risk of seal leakage fractionating sample, and allowing contamination
- The science return can be significantly improved (and in some cases dramatically so) by one or more of several strategies to obtain at least one gas sample that has not equilibrated with a solid.
  - Have M2020 collect a gas sample in one of its empty RSTA tubes (volume ~13 cc).
  - Collect gas in a newly designed, valved, RSTA-sized tube that is flown on either SFR or SRL.
  - Add a larger (50-100 cc) dedicated gas sampling volume to the OS,
  - Add a larger (50-100 cc) dedicated gas sampling volume to the OS, fill it with compressed martian atmosphere.
- Options for collecting a dedicated gas sample by SRF or SRL should be investigated. If this implementation is not possible, then Mars 2020 should be directed to use one or more sample tubes for collection of an atmospheric gas sample

Integrated Timeline (Shown for 2033 Return)



Recommendations for Future Work

1. Constrain the optimal storage conditions in order to fit time-sensitive investigations within an optimized sample workflow in the SRF.
2. Define the sterilization methods and parameters that will be approved for use, including the sterilization-chamber atmosphere, and potential non-traditional sterilization methods (e.g., filtration of gas samples, acid hydrolysis of solvent extracts).
3. Sample-related engineering developments: secondary container for samples tubes once removed from the OS (i.e., STIC concept); determine how best to open the sample tubes; headspace gas extraction techniques
4. SRF planning: develop specific requirements for environmental conditions, contamination control, and constrain priorities related expected timescale for sample